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TORONTO CECIL TS - GROUNDING SYSTEM TESTS

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Simulated fault current tests were conducted at Toronto Cecil TS to measure the station ground potential rise, touch voltages and pipe cable shielding efficiency at power frequency. The measured results were found to agree reasonably with the previously calculated values. The station ground potential rise and touch potential for an ultimate HV fault current of 33 kA are well under safe limits. A revised model to include the impedance of the oil feed pipe is presented.

1.0 INTRODUCTION

Toronto Cecil TS is an indoor SF6 station located in downtown Toronto. The grounding system at the station is characterized by an extensive network of HV cable pipes and LV distribution neutrals installed in an underground duct system. The area is also congested with other underground services. At the request of Stations and Transmission Programs Department, detailed calculations based on estimated parameter values were previously done in order to evaluate the 60 Hz grounding system performance at the station. Soil resistivity at the station was also tested at that time. These calculations and results are described in a previous Research Report/1/ and need to be validated by field measurements.

Meanwhile, as a result of another study to investigate a cable pipe burn-through at Cecil TS in 1984, Electrical Research Department was requested by the Stations and Transmission Design Department to conduct field tests at the station to measure power frequency and transient voltages stressing the GIS-pipe cable interfaces and the oil feed pipe interfaces. This opportunity was taken to measure also the ground potential rise, touch potentials and pipe cable shielding at the station in order to validate the previously calculated values.

2.0 TEST PROCEDURE

Tests were conducted at Cecil TS under simulated fault conditions on September 9 and 10, 1987 to measure the power frequency grounding system performance and the power frequency and transient voltages appearing across the SF6 interfaces. This report covers only the power frequency grounding system tests and a separate report /2/ covers the remaining part.

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Figure 1 gives the grounding system interconnections at Cecil TS at the time of the tests. The 115-kV pipe-type cable circuit C7E between Cecil TS and Terauley TS was taken out of service and working grounds were installed at Terauley TS on all the three phases of the circuit to sink the test current. A test current of about 10 A at 67 Hz was injected into the three parallel phases of the remotely grounded test circuit and the following measurements were made:

- (a) Unshielded station ground potential rise, station touch voltage, fence touch voltage and current splits on HV cable pipes.
- (b) Shielded ground potential rise and cable shielding.

A typical HV pipe-type cable circuit at Cecil TS is shown in Figure 2. The cathodic protection of the test circuit was temporarily isolated at both ends and the oil feed pipe was directly grounded at the Terauley end, leaving the cable pipe floating at the Cecil end for the tests under (a) above. To measure the shielded parameters in (b) above, the cable pipe was directly grounded to the SF6 enclosure at Cecil end by jumping SR to CR in Figure 2. On all other cable circuits, the cathodic protection was temporarily isolated and the oil feed pipes were directly grounded at both ends to allow measuring ground current splits. The station ground potential rise was measured between a remotely grounded conductor and the local station ground. This was done using a Bell Telephone cable remotely grounded at Bell centre, a Hydro communication cable remotely grounded at Head Office, a fire hydrant, a water fountain and a nearby manhole cover.

An HP3310 function generator in conjunction with two KEPCO amplifiers provided the required test current. Figure 3 shows the current injection circuit. Potentials and currents were recorded with respect to 1.0/0 A injected current. An HP3582 network analyzer in conjunction with a differential amplifier was used to measure the ratio of the two inputs including phase angle. The analyzer reference current and the current splits on the cable pipes were measured using two Ritz clip-on 5 VA, 150:5 A CTs with 0.66 Ω shunts. A patch panel allowed interfacing between the field and the instrumentation wirings. Fused gas tube protectors were used to limit the potential to local ground in the event of a system fault. The frames of the instrumentation were bonded to the station ground using heavy short wires. Barriers were provided around the isolated ground switches and the test area for personnel safety.

Assistance was obtained from Central Region staff in co-ordinating the tests, applying for the above outage, making temporary connections to the cable circuits, and in conducting the tests.

3.0 TEST RESULTS

3.1 Unshielded ground potential rise

With the cable pipe of the test circuit floating at the Cecil end, the ground potential rise was measured between the local station ground and the various remotely grounded conductors. Table 1 lists the measured results. The ground potential rise measured using the remotely grounded Bell Telephone pair and the Hydro communication pair were corrected to take into account an estimated shielding factor of 0.9/-15.

TABLE 1

CECIL TS - MEASURED UNSHIELDED GROUND POTENTIAL RISE

	<u>Measured on</u>	<u>GPR (mV/A)</u>
(1)	Bell Tel. Pair	13.8/ <u>62</u>
(2)	Hydro Comm. Pair	12.3/ <u>47</u>
(3)	Fire Hydrant	15.4/ <u>47</u>
(4)	Manhole Cover	15.5/ <u>47</u>
(5)	Water Fountain	16.9/ <u>48</u>

3.2 Unshielded Touch Potentials

Touch voltages (the potential difference between a metallic object and a point one metre away on the earth's surface) were measured at several locations at the station. The maximum value of about 6.5/42 mV/A was measured on a private metallic fence which separates an iron station fence from an adjacent public walkway along the east side of the station. A voltage of about 3.4/41 mV/A was measured between the two fences. Touch voltages of about 1.8/61 mV/A and 0.2/58 mV/A respectively were measured on a water pipe and on a manhole cover at the station.

3.3 Unshielded current splits

Table 2 shows the current splits measured on the HV cable pipes. Considering the technical difficulty in measuring current splits on the thirty-three distribution neutrals and time constraints, no attempt was made to measure the splits on these neutrals.

TABLE 2

CECIL TS

MEASURED CURRENT SPLITS (UNSHIELDED) ON HV CABLE PIPES

<u>HV Cable Circuit</u>	<u>Current Split (A)</u>
Injected to C7E	1.000/ <u>0</u>
C5E	0.333/ <u>8</u>
L12C	0.029/ <u>12</u>
L9C	0.012/ <u>48</u>
H8LC	0.026/ <u>-30</u>
H6LC	0.027/ <u>-22</u>

3.4 Shielded Ground Potential Rise

With the cable pipe of the test circuit bonded at both ends, a ground potential rise of about 1.71/65 mV/A was measured using the remotely grounded Hydro communication pair. Here also, the actual measured value was corrected to take into account an estimated shielding factor of 0.9/15 for the communication cable.

3.5 Shielding Efficiency of Cable Pipe

For 1.000/0 A injected to the HV test circuit C7E, current splits of about 0.905/5 A and 0.018/29 A were measured on the cable pipes of the test circuit C7E and the parallel circuit C5E respectively.

4.0 DISCUSSION

- (a) The measured ground potential rise (GPR) of 1.71/65 mV/A for a HV fault on circuit C7E compares reasonably with the previously calculated value of 1.3/19 mV/A /1/. Here, the model is based on fault current infeed from all the three sources /1/. For an ultimate HV fault current of 33 kA, the measured GPR is about 56 V and is well under the recommended limit of 3 kV.
- (b) The impedances of the short length of the oil feed pipe and that of the polarizing cell and its connecting lead at each end of the cable circuit were neglected in the previous model /1/. Based on a Carson's earth return self impedance of about 0.679/79 Ω /km for the oil feed pipe (formulas given in /3/), 0.5 m Ω for the polarizing cell (from manufacturer's data) and 10 μ H for the cell connecting lead (from measurements /2/) a lumped self impedance of about 71/82 m Ω was calculated for about 80 m of the oil feed pipe at both ends of the HV cable circuit. This additional self impedance results in a net shielding factor of about 0.040/28 for the HV double circuit pipe cables as compared to the previously calculated value of 0.012/98 /1/. The corresponding calculated GPR is about 1.76/40 mV/A for the test condition.

Further, the previous model /1/ assumed that the HV double circuits C7E (test circuit) and C5E between Cecil TS and Terauley TS are in parallel for the entire distance, but actually these are in parallel for only about 72% of the distance. These and other assumptions in the model /1/ may have resulted in a lower calculated GPR at Cecil TS compared to the measured value. However, since the GPR at the station is considerably below the recommended limit, the error due to these assumptions is not critical and a revised model for an actual fault condition is not considered necessary at this time.

- (c) The measurements indicated that about 0.92/4 pu of the total fault current returns through the cable pipes of the faulted circuit and the parallel circuit. The corresponding calculated value is about 0.97/1 pu for the test condition. Impedance of the test leads may have resulted in a lower measured value. Thus, only about 0.11/40 pu enters the remaining station grounding system as measured. The station ground potential rise is greatly reduced as a result of this shielding effectiveness of the HV cable pipe. The present calculated shielding factor of about 0.04/28 does not appear to be conservative when compared to the measured value and some adjustment in the model is needed.

- (d) The station ground current component could not be estimated from the measurements since the current split on the LV distribution neutrals was not measured. However, the previous calculations have indicated that the LV distribution system with its many remotely grounded parallel feeder neutrals is the main contributor in reducing the interconnected station ground impedance. As a result, the isolated station ground potential rise is not an important parameter.
- (e) Based on the previous model/1/, the unshielded GPR for the test condition was calculated as 13.9/69 mV/A and this compares reasonably with the measured values (Table 1).
- (f) For an ultimate HV station fault current of 33 kA and a shielding efficiency of about 11%, the touch voltage as measured on the private fence along the east side of the station is about 24 V. This is well below the tolerable limit of 169 V calculated for the station /1/.

5.0 CONCLUSION

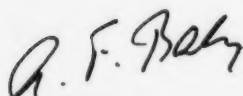
- (a) The maximum measured ground potential rise at Cecil TS is about 1.71/65 mV/A with the HV cable pipe shielding and 16.9/48 mV/A unshielded. For an ultimate HV fault current of 33 kA, these are respectively 56 V and 558 V and both are well under the recommended limit of 3 kV.
- (b) The shielding effectiveness of the HV cable pipes considerably reduces the fault current entering the station grounding system. About 0.92/-4 pu of the injected current returned through the double circuit cable pipes as measured and only 0.11/-40 pu enters the remaining station grounding system. As a result, the station ground potential rise is considerably reduced.
- (c) The impedance of the short length of the oil feed pipe was neglected in the previous model /1/. A revised calculation to include this effect results in a reduced pipe shielding effectiveness. However, since the GPR at Cecil TS is considerably below the recommended limit, the error due to this assumption is not critical. But for other stations the impedance of the oil feed pipe may be important.
- (d) The present calculated shielding factor does not appear to be conservative when compared to the measured value.
- (e) The maximum measured touch potential of about 24 V for an ultimate HV station fault current of 33 kA is well below the tolerable limit.
- (f) The measured results at the station are found to agree reasonably with the previously calculated values /1/.

6.0 RECOMMENDATION

- (a) The impedance of the short length of the oil feed pipe may be important in grounding system design for other stations and therefore should be included in the calculations.
- (b) More field tests involving HV cable pipe shielding would be useful to validate the model.

Approved:

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REFERENCES

1. P. Pillai, "Toronto Cecil TS - Grounding System Studies", Ontario Hydro Research Report No. 86-155-K, June 25, 1986.
2. P. Pillai, "Toronto Cecil TS - GIS/Cable Interface Arresters Power Frequency Overvoltages and Energy Rating", Ontario Hydro Research Report No 87-305-K, Jan 18, 1988.
3. E.P. Dick, "Strachan TS Grounding System Calculations", Ontario Hydro Research Report No. 83-433-K, November 7, 1983.

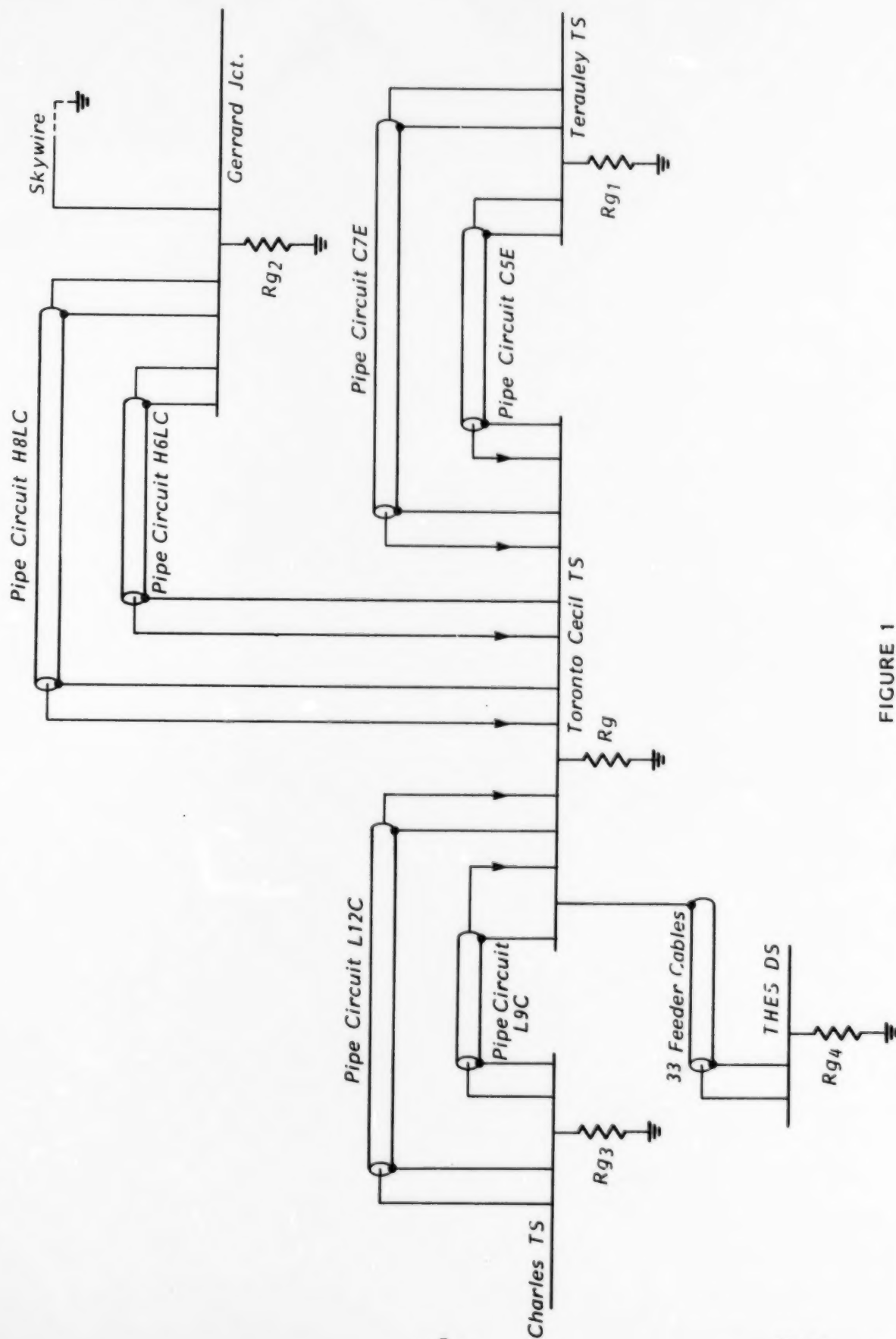


FIGURE 1
GROUNDING SYSTEM INTERCONNECTIONS
TORONTO CECIL TS

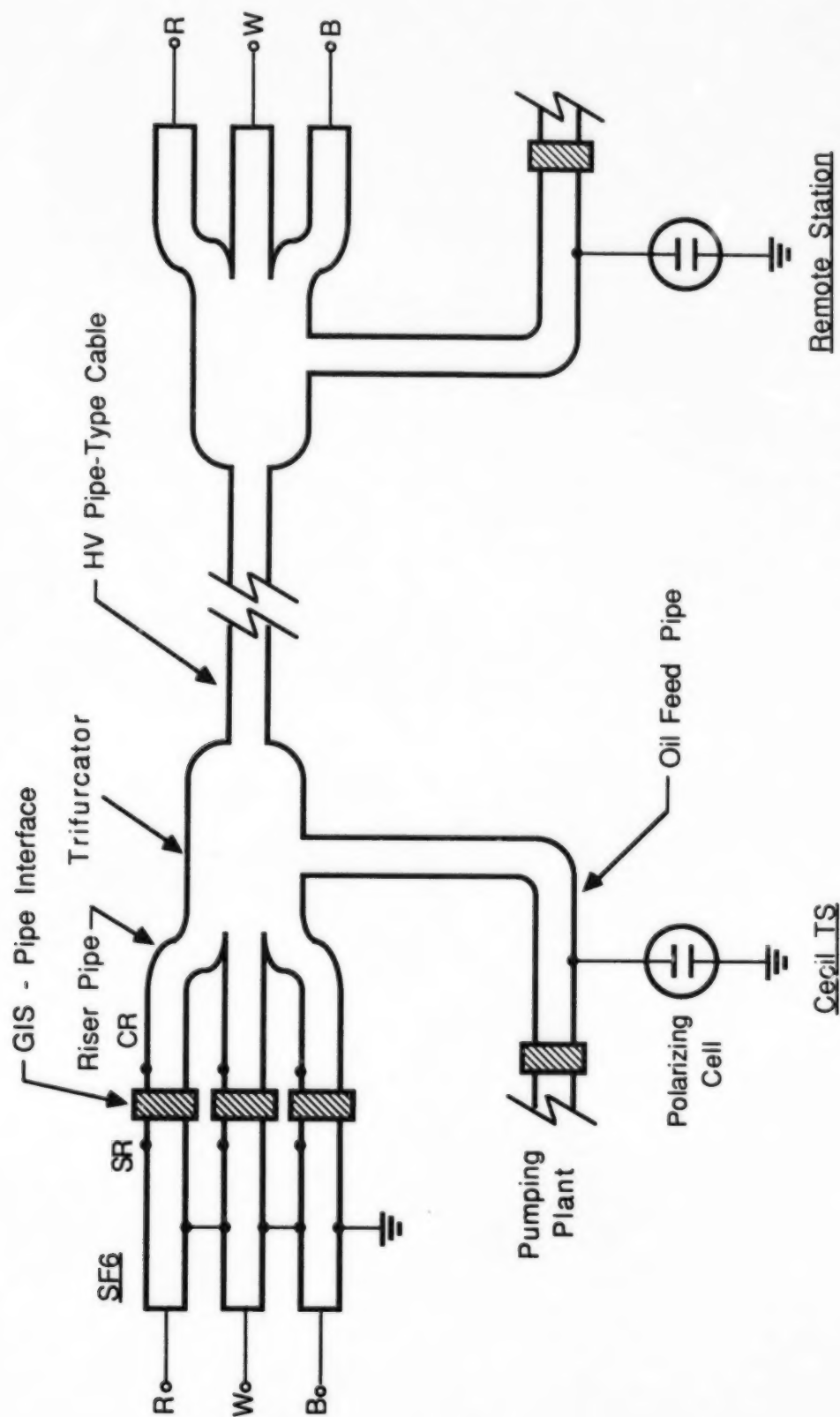


FIGURE 2
HV PIPE-TYPE CABLE CIRCUIT
TORONTO CECIL TS

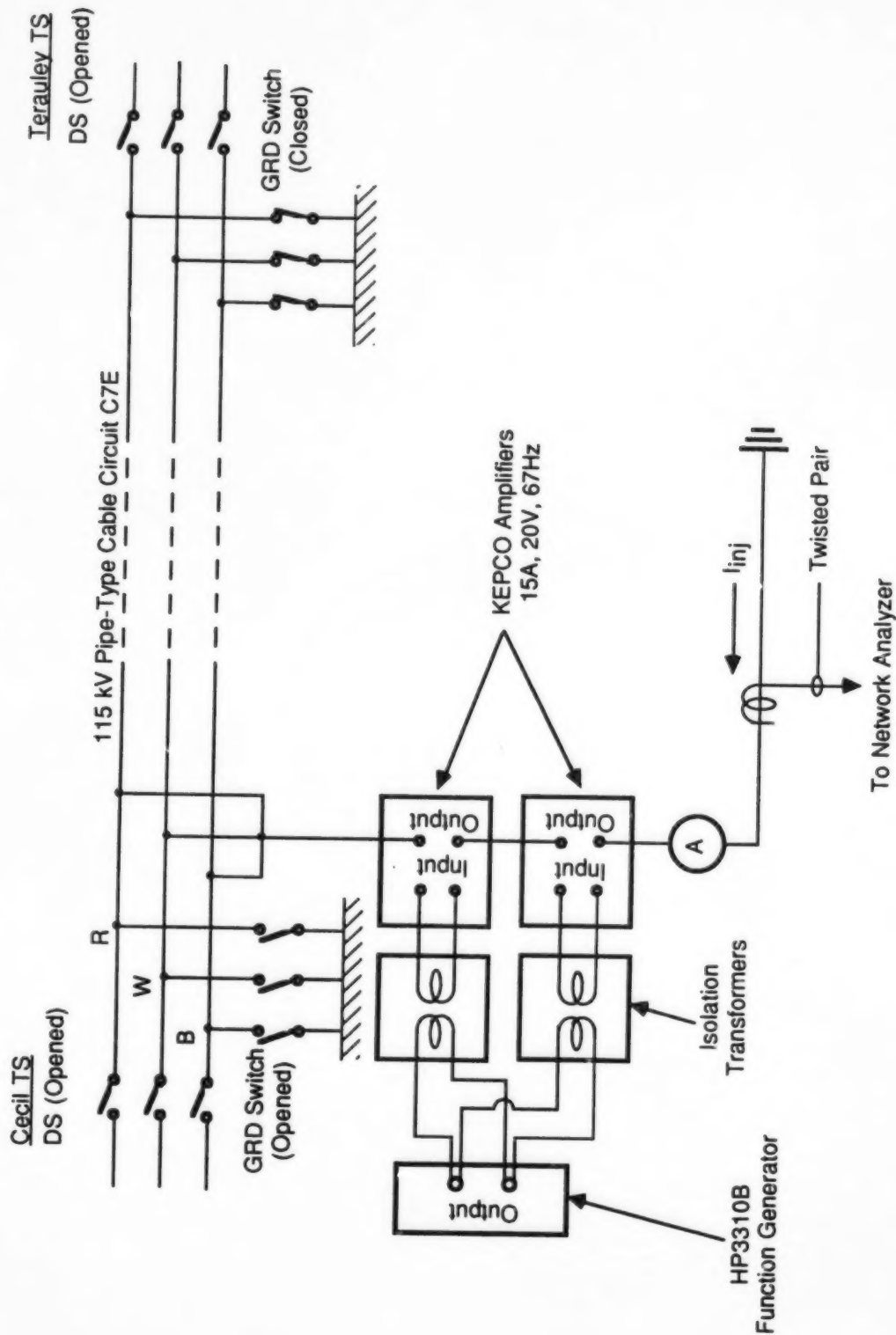


FIGURE 3
GROUNDING TESTS - FAULT SIMULATION CIRCUIT
TORONTO CECIL TS